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# A Review Of Inventory Control Theory

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Department of Industrial Engineering
The University of Buffalo

## INTRODUCTION*

The mathematical analysis of inventory systems and the consequent theory of inventory control are neither new nor complete. In the present paper, an attempt is made to review the published literature, from Babcock's first paper to the present. It is hoped that this review will save the researcher in the theory of inventory many tiresome hours of wading through work irrelevant to his interest, and at the same time point out the evolution of the main lines of thought in his area. In addition, the review may aid the practitioner in the field by giving him direct access to models or papers on problems similar to his. This may save him the time of developing his model from "scratch" or, perhaps, of developing any model for himself.

Because an undertaking such as this must be limited, it has been chosen arbitrarily to follow the "Purchasing Model", where this deviates significantly from the "Production Model". Deviations have occurred mainly since 1954, and those interested can pursue the subject using the work of Arrow, Karlin and Scarf, or Modigliani, Holt, Simon, Schaefer and Culbertson.

## 1912-1950

The earliest attempts to determine a mathematical basis for the control of inventories stemmed from the manufacturing

---

*Reference numbers in this paper pertain to the Bibliography at the end of the article. If two reference numbers are given, the first pertains to the bibliographical reference and the second to the page or pages of such reference.

industries, and constituted the problem of economic lot sizes. Characteristically, these problems depended on known and constant demand rates and either instantaneous input to stock or known and constant input rates. Given these two conditions, along with the cost of holding the finished product, the problem was then to find the number of units to be manufactured for each set-up, so as to make the yearly charges for set-up and storage equal (the "balancing" problem), or to make the sum of these costs a minimum (the "minimum cost" problem).

The earliest known work published in this vein was by George D. Babcock, based on work done in installing the Taylor system in the Franklin Manufacturing Company in 1912.[16] Though his paper does not develop the model, it is known that he attempted to equate set-up costs and "capital costs" (apparently the interest charges on money tied up in finished goods). This approach gave rise to a cubic equation.

Following Babcock, Ford Harris[79] developed what is known as the classical square-root solution to the problem -- though his approach was similar to Babcock's, in that the attempt was made to equate set-up costs and carrying costs. The equation, which gives rise to a square-root function, undoubtedly was simpler. The solution, on which was based most of the subsequent refinements up until 1930, was given in the form

$$Q = \sqrt{\frac{DS}{C} K} \quad ,$$

where Q is the economic lot size,
D is the daily demand,
S is the set-up costs,
C is the unit production costs, and
K is a constant.

The next major development, in the basic theory of inventory analysis, occurred in 1918, when E. W. Taft[181] dropped the previous assumption that production of the finished product occurred at an instantaneous rate.

Morse in 1918,[133] Taft in 1918,[181] Camp in 1922,[31] Cooper in 1926,[41] and others, revised the cost considerations to allow specific recognition of interest charges on work in storage and in process, rent charges for storage area occupied, and depreciation and obsolescence charges on the stored items. However, each of these changes in costs retained the basic structure of the problem, as developed by Harris and modified by Taft.

In 1922, J. A. Bennie[22] attempted to include in his stock model the cost of stock held to protect against unexpectedly large demand -- safety stock. R. C. Davis, in 1925,[46] in turn introduced this concept, and explicitly included the costs of this reserve stock in determining the optimum lot size.

Davis' 1925 article introduced, in addition to the cost of stock held in reserve, the elements of a theory of lead time. Heretofore, lead time was a non-existent variable, since input was assumed sufficiently great that production in anticipation of sales was unnecessary. Davis' 1925 model allowed specifically for production in anticipation of sales (though, of course, the sales were still assumed to be at a constant, known rate).

The culmination of this early work in the production model occurred in 1928, when F. E. Raymond,[154] under the auspices of the Management Section of the ASME, published his article, "Economic Production Quantities". This work was expanded, and, with but few exceptions, the publication of Quantity and Economy in Manufacture[159] in 1931 may well serve as the definitive treatise on the classical production model. This monumental work (requiring some 350 pages to develop, and ending with a "simplified" formula containing 12 symbols, most of which were composed of more basic variables) attempted to find the production order size by examining all the variables previously considered. In addition, while the assumption of known and constant demand rates was retained generally, the simplified assumptions of known and constant

production rates were dropped. Raymond examined several input rates (all deterministic) not necessarily constants. Costs that were included were: (1) production costs (composed of material, labor and overhead); (2) manufacturing costs (composed of production costs and set-up costs); (3) investment costs on capital tied up in inventories (with examination of both the case where interest was charged on the manufacturing cost, and where it was charged on the "ultimate unit" cost); (4) work-in-progress costs; (5) rent costs of storage area (based on volume of space taken up by storage); (6) deterioration costs of goods in storage; and (7) obsolescence costs on goods in storage.

In addition to cost considerations, Raymond included a short discussion of variable-demand patterns. Brief reference was given to statistical methods of polynomial-curve fitting to use as a demand estimator; and, finally, the effects of the "sales" period were introduced.

Raymond, in his book, makes the curious observation that the lot size which minimizes cost may not be the same as that which is most economic. This was apparently a result of the general approach to the problem during much of this time. Raymond and others did not minimize a function for total costs, but rather a function for unit costs. Lewis[112] pointed out that the minimum unit-cost point was not necessarily the highest-profit production point even if unit selling-price is constant. Depending on the elasticity of the cost curve, the minimum cost point could give rise to the maximum total profit, but not necessarily. This led Raymond to define a range of lot sizes between a value defined by the minimum cost point and the economic cost point. This latter was defined as that quantity which can be produced at lowest total unit cost consistent with an economical use of capital.*

---

* The problem is bypassed if the equation to be minimized is the total cost equation, and this seems to be the presently existing approach. For a further discussion of Raymond's argument, see Ref. 159:5.

With this one piece of work, the classical field of lot-size analysis was essentially closed, although R. C. Davis, in 1936,[48] specifically attacked the problem of work-in-process storage. Writers following Raymond certainly were hard pressed to find something new to discuss, under his assumptions.

One concept worthy of short mention arose, during this period, in 1928, when R. C. Davis presented his paper, "Economic Purchase Quantities", to the Management Section of ASME. Prior to this, all of the analysis was aimed at the production problem, and though the authors often commented on the purchasing problem, it was not until Davis' paper that work was undertaken specifically on the problem of purchasing and the inventory of raw materials. With the obvious redefinition of costs necessitated by the problem, Davis' purchase model differed little from the Harris production model of 1915. He did, however, include a lead-time concept, but again this was little different from his lead-time concept in 1925. Perhaps the value of this paper is that it opened the purchase problem to analysis at the time that Raymond's work was closing the production problem for a time. This conjecture rests on the fact that, with few exceptions, the production problem seems to disappear from the inventory-analysis literature for ten years, while several articles appear on the purchase problem.

As has been seen, the inventory problem, from its inception, could be characterized by two factors -- deterministic variables and static behavior. Once these two assumptions are made, the extension of the resulting analysis is relatively limited. New costs can be introduced, new demand shapes can be tried, minimum-cost versus economic-lot-size arguments can rage, and purchase-versus-production models can be built. This is, in fact, what happened throughout most of the period 1912-1930. In spite of these concepts, the analysis was still static and determinate.

Two papers introduced in 1927-1928, and two more in 1938-1939, started the field of inventory analysis on an exodus from its straight-jacket of determinancy. Strangely enough, none of these four papers has received the attention, as an historical document, that it deserves.

Writing in March of 1927, Pennington[148] makes the comment:

> Of course, in practice, the new lot will not always, perhaps not usually, arrive on schedule. Or sales may suddenly increase and use up one lot before the next arrives. To provide for such emergencies the reserve stock M is carried. Having this reserve we may forget the unexpected and calculate the most economical value of the first quantity L with positive precision.*

With this as a start, the author then proceeds to determine the order quantity and reorder point, under the assumption that demand and delivery behave as expected. Up to this point, there is little significant difference between this model and Davis'. However, following the line of thinking set forth in the quoted paragraph, Pennington next poses the problem of determining the reserve stock for the non-expected conditions.** It is here that the true value of the paper lies. Using as a criterion,

> "The best value of M will be that which most nearly balances the probable losses resulting from occasional failure to make prompt shipments against the cost of maintaining this reserve",***

the author then spells out the necessary variables and costs, including, for the first time, the concepts of the cost to run

---

*Pennington, Gordon, "Simple Formulas for Inventory Control", Manufacturing Industries, Vol. 13, No. 3, March 1927, p. 199.

**In spite of his acceptance of emergency or reserve stock in the 1928 article, Raymond in his book was content to pass emergency-stock calculations off to executive judgment. This, in spite of the fact that the only justification of his work is to assume he was trying to put inventory control on a "scientific" basis, instead of the "executive judgment" basis it had previously been on. A lack of understanding of the stochastic nature of the problem may well have led Raymond to ignore this important point, in an otherwise monumental piece of analysis.

***148:202

out,* and variable delivery time.** From here the problem is solved to find that emergency stock defined as optimum.

Pennington's analysis of the problem is at best crude. His probability arguments are elementary and his separation of order quantity and reorder point is in error,*** but, except for the addition of dynamic elements, the basic inventory problem considered by most present writers was in this article of thirty years ago.

Closely following Pennington's work, Fry[68] in 1928 attacked an inventory problem wherein demand for the product was allowed to be a random variable (Poisson distribution). Using a criterion of fixed run-out probabilities ("How many packages [of dog biscuits] should be adopted as the standard Monday-morning stock, in order not to lose more than one sale out of a hundred"), he was able to find the probability of running out of stock as a function of the maximum quantity stocked. From this the quantity to be stocked for fixed run-out probabilities was immediately found.

In a series of articles starting in 1934, Wilson[203] took Fry's work and superimposed the necessary cost considerations, apparently retaining (he did not spell out, explicitly, the mathematics of his work) the classical Davis model for determining order size and including separately -- as Pennington did -- calculations to determine emergency stock.

Pennington, Fry, and Wilson thus took the inventory problem its first step beyond the purely deterministic problem of the

---

* "W = The value of loss of business or good will, in dollars per day, resulting from inability to fill orders beyond the period Q." 148:202

** "V = The probable delay in receipt of new lots beyond the period T estimated in days." 148:202

*** See 200:56-62.

earlier writers, by introducing probability concepts. The fact that Fry, and, apparently, Wilson, assumed Poisson demand, is of little consequence compared with the fact that they broke the bounds of the restrictive assumptions made by Raymond and his predecessors.

It is interesting to note that the bulk of work stemmed from the engineer, throughout most of the period to 1930. With few exceptions, the work being undertaken in the field of inventory analysis ignored the field of economics -- its logical confrere. This lack of knowledge was not one-sided, however. With probably no exceptions, until 1938, the field of economics ignored the work taking place in the problem of inventory analysis. However, starting with Edgeworth in 1888,[57] and continuing parallel to the theory of inventories, the economist showed interest in the field of money-demand analysis.* Finally, in the period 1938-1940, a series of articles appeared by the economist, which began to tie together the efforts made in the two, previously diverse, attacks. Schneider and Jessen, in 1938,[197] Smithies[177] and Abramovitz[2] in 1939, and Shaw[170] in 1940, in the field of economics, opened the problem of inventory control to its dynamic considerations. To this work we now turn our attention.

Whitin,[197] commenting on the work of Schneider and Jessen,** sets up their problem as: Given a manufacturer's sales forecast as a function of time, his initial inventory, his capacity restrictions, carrying charges and production costs, how should he schedule his production in order to minimize costs involved in production and storage adequate to fulfill sales requirements?

---

* For an excellent discussion of the parallel concepts in inventory analysis and economics, as well as an interesting history of the growth of each, see Arrow, Karlin and Scarf, Studies in the Mathematical Theory of Inventory and Production (Stanford University Press, Stanford, Calif., 1958), chap. I.

** Unfortunately, the work of Schneider and Jessen done in 1938 was in German and is not readily available for our use. Instead, we follow Whitin's discussion.

From this starting point, they proceed analytically and graphically to determine the production as a function of time, subject to both linear and non-linear sales and cost curves. In all cases, the variables are deterministic. As a consequence of assuming constant selling price, demand for the product, though known, is not subject to change by the company, though it may change due to exogenous conditions (seasonal fluctuations, for example). Because of this lack of control over selling price, the problem solved by Schneider was again a cost minimization.

In 1939, Smithies approached a problem similar to Schneider's, but allowed unit price to depend on quantity sold.* As a consequence, the revenue curve, as well as cost curve, is under the control of the company, and the classical problem of cost minimization now has to be replaced by profit maximization. (As long as the company has no control over sales, either through price discounts or some other method, the problem of cost minimization and profit maximization facing the analyst is the same problem. As soon as the firm has some control over its revenue function, the problem of cost minimization is inadequate to the analysis. A concept such as this may have been the point of Raymond's argument for an Economic Lot Size Formula, as opposed to a Minimum Cost Formula.) Using methods of the calculus of variation, Smithies was able to determine explicit functions for the sales and production rates as a function of a continuous time parameter.

Abramovitz, in 1939,[2] and Shaw, in 1940,[170] added the concepts of risk to the production problem, but in each case this is not done by an explicit examination of random variables, but by the method of handling the revenue and cost functions.

Massé, in 1946,[122] seems to have been the first person to successfully introduce risk concepts into the problem of dynamic inventory systems, but unfortunately his two volumes, comprising about 375

---

* "[Let] P = P(S,T) be the unit price at time T if the annual rate of sales is to be S." 177:314

pages with both deterministic- and random-demand analysis, have not been translated.

With the publication of the Massé paper, the field of inventory analysis had examined most of the elements of inventory control. Edgeworth, in 1888, had introduced the problem of demand for money, and had adopted some elements of probability theory in his work. The inventory problem (No. 1) of Eisenhart[59] follows this approach. By 1912, Babcock had opened the field of production control to mathematical analysis, and by 1930 Raymond had closed the classical field, leaving it under assumptions of strictly deterministic variables. Starting before Raymond's work, and continuing to the present, Pennington first, then Fry, Wilson, Pitt and Eisenhart opened the inventory problem to questions of random demand and, in one case, random supply. During the years 1912-1940, the economic problem of demand for money more and more paralleled the inventory problem, and in 1938 Schneider brought forth the production problem (one level of abstraction from the classical lot-size problem), including elements of dynamism. Abramovitz and Shaw, in 1939-1940, introduced the ideas of probabilistic behavior to the dynamic problem with probability variables, in a more rigorous fashion.

Thus we are able to conclude, as does Arrow:[13:19]

> Most of the elements of modern inventory theory are found somewhere in the preceding discussion ...
>
> It is the integration of these elements into consistent wholes, and the determination of optimal policies for models encompassing numerous features, that have been the focus of current research in inventory theory.

It is to these models in current research that we now turn our attention.

## AFTER 1950

### I. THE ARROW, HARRIS, MARSCHAK APPROACH

Whereas Raymond, in 1931, was able to comment on the 38 models and numerous slide rules, graphs, charts, nomographs and other mechanical aids that were in existence prior to his work, a writer in the present would be hard put to count the models alone that have emerged since 1950. Some of these return to the early concepts of Raymond and his predecessors,* others develop results from the theory of purchasing, reorder points and optimum lot size by methods similar to those developed by Pennington, Fry and Wilson.** However, the most prodigious amount of work has been done following the lead of Schneider and, particularly, of Massé. It is to this work that we devote most of this section.

The first integration of previous concepts appeared in 1951, in the work of Arrow, Harris and Marschak (AHM).[12] In this paper, the authors examine three problems in the general field of purchasing. They first review the classical purchase equation of Davis, and examine further the question of "when to buy". Included in the analysis is a "utility function" as well as the classical cost concepts. Their first model retains the classical assumption of determinancy and static behavior, and their results naturally are close to those of Davis and Raymond. (They are not identical, in that AHM allow price discounts on the purchased items, as a continuous function of the quantity ordered. Wilson also had examined the effect of price discounts, but, generally, the work prior to 1930 omitted this.)

---

* See, for example, W. Evert Welsh, "Economic Order Quantity Buying", New York Purchasing Review, Vol. 1, No. 3, January 1956; also, S. Bhattacharjee, "Economic Manufacturing Lot Size", Journal of Industrial Engineering, Vol. VIII, No. 2, March-April 1957; and Wayland P. Smith, "An Investigation of Some Quantitative Relationships Between Breakeven Point Analysis and Economic Lot Size Theory", Journal of Industrial Engineering, Vol. IX, No. 1, January-February 1958.

** For example, 62:160-177.

Following this deterministic approach, the authors introduce concepts of probability into the demand curve, but retain the static assumptions along with instantaneous inputs, to arrive at their "Static Model with Uncertainty". It is here that some of the loose threads of previous analysis begin to be tied together. A revenue function, price discounts, and run-out costs are added to the previous models, and from there a cost curve is evolved. The classical approach of minimization is used to arrive at conditions necessary and sufficient to find the optimal level of stocks to hold at the beginning of the one (static) time period considered. These results are then tied in with the classical formulation of Fry, to allow for criteria based on either run-out costs or run-out probability.

From the purely static problem, AHM turn to the real contribution of their paper. Retaining the assumption of probabilistic demand, but otherwise simplifying the costs of the static model, they introduce the true policy problem of finding the optimal inventory parameters for a dynamic system. To accomplish this, two parameters (s,S) are introduced, such that if stocks at the end of a period are less than s, a quantity is ordered to bring them (immediately) up to S. If the stocks are greater than s, nothing is ordered.* The problem then is to find those values of s and S, so as to minimize a loss function. The problem of losses occurring at different periods in time, over an infinite horizon, is resolved by introducing a discounting factor, so that the loss to be minimized is the present value of all future losses.

At this point, the elements of the purchasing problem are almost as comprehensive as those which exist today. Random demand has been introduced. Dynamic concepts have been brought in. Decisions are completely based on cost concepts, instead of hybrid

---

* Beckman and Muth[19] and others have called this two-parameter policy the "two bin" policy. However, it does not seem to be the classic two-bin system examined by most early writers and fully discussed by Whitin.[20] The AHM (s,S) policy appears to be a combination of the two-bin and ordering-cycle systems.

units containing partly cost concepts and partly non-cost concepts (fixed probability of running out). Perhaps the only piece of work even nearly comparable to this is Pennington's in 1928. The authors are careful to point out, however, that their work is not complete, and, in a final section, they spell out the problems still unsolved in their approach.

The first paper to examine the AHM work, critically, appeared in 1952, and was followed by two additional papers in 1952 and 1953. Dvoretsky, Kiefer and Wolfowitz (DKW) examined the AHM paper in detail in the first of these papers ("The Case of Known Distribution of Demand"[53]), and they were able to show that much of the classical work, including AHM, was based partly on erroneous assumptions. Starting with an examination of the AHM static model, DKW showed that under some cost conditions the assumed (s,S) policy or two-parameter policy need not yield the optimum system. This criticism leads to a new dimension to the inventory problem. Heretofore, nearly all writers in the field had assumed the two-parameter policy as given (the policy was called the two-bin system), and directed attention to deriving the parametric values necessary to minimize costs under that policy. The DKW approach questioned these policies, and, for the AHM static and dynamic problems, it showed that the (s,S) policy need not be the best of all policies. Further, DKW showed, for the dynamic problem, that if the (s,S) policy were optimum, the parameters need not be constants from period to period. These considerations, coupled with the ensuing analysis in the same vein, can be considered as one of the important contributions to the field of inventory control.

Following their rather iconoclastic start, DKW proceeded to set up several problems in the field of inventories and find the optimum policies for some of these. One of the problems examined is a truncated version of the AHM dynamic model. Here the future is considered finite, and the AHM model emerges as a limiting form. Another problem posed -- and here the policy is not found explicitly -- is the problem of randomly-arriving supply. With the exception of Pennington's work, no other author had yet

examined this important concept. A third problem posed in the basic paper of DKW is that of controlling the inventories of several items -- the aggregation problem. Wilson had studied this problem to some extent, but the DKW approach, assuming dynamic behavior, random demand, demand derived by the substitution between items in the aggregate, and the generalized cost structure, is much more general.

In 1952,[54] DKW again attacked the classical structure of the inventory problem by critically examining the assumptions placed on the demand distribution of the problem. Heretofore, writers in the field had made specific assumptions concerning the distribution of demand. For example, Fry assumed the demand to be Poisson-distributed; AHM assumed generalized, but known, demand functions. DKW in their second paper posed the question of behavior in the event that the demand distribution is imperfectly known. They attack the problem of optimal behavior when only estimates of the demand-distribution parameters, based on historical data, are given. Using min-max methods, they maximize the minimum expected gain over all distributions of a given class with the given parameters. With these methods, they retrace their steps in the first paper, to examine static and dynamic behavior as well as the problems discussed above.

In a third paper in 1953,[55] DKW adopted a mode of attack that served as a guide for much of the subsequent work in the inventory problem. Having shown in their first paper that the simple ordering policies need not be optimal, DKW here turn the question around to ask what conditions on the cost and demand functions make the (s,S) policy for the AHM static model the optimal policy. The problem, at this point, gets away from the more classic approach of parameter setting for a given policy, and adopts the mathematical approach of uniqueness and existence. Staying within the framework of the static AHM model, DKW examine necessary and sufficient conditions for the demand function, so as to make a simple ordering policy optimal under varying conditions of the cost parameters.

Bellman, Glicksberg and Gross (BGG), in 1955[20] modified the

third paper of DKW to ask the question: For a given demand function, what conditions hold for the cost functions, so that an inventory system can be made optimal by setting a single variable (the fixed stock level)? The problem is pursued, using the concept of functional equations (of which the AHM model is an example), and defining optimal as minimum cost. The paper assumes two costs: (1) the cost of ordering to meet expected demand; (2) the cost to order to meet excess demand. Assuming costs to be proportional to quantities ordered (for either ordering), necessary and sufficient conditions are found for the constant stock level for infinite time spans. It is shown that a single level for all future periods can be used. (DKW had shown that under some conditions an s,S policy may be optimal if s and S are functions of the periods -- they can change from period to period.)

Generalizing this problem, they next pose the problem for multiple products, finding some possibilities of sub-optimization.

As soon as the assumption of linear costs is dropped, however, the possibility of finding a single stock level, that is constant over time, appears to vanish. BGG examine this case and find the necessary conditions that the constant stock level be retained, and discuss examples of the general non-proportional run-out costs case.

Finally, fixed time lags are examined, and the optimal policy is found (as a function, the initial stock level) for the infinite "horizon" case.

Continuing the area opened by Arrow, Harris and Marschak, Beckman and Muth, in 1956,[19] extended their results formally by introducing the fixed time lag of inputs, explicitly.

Rosenblatt,[163] in 1954, added a new problem to the inventory field. Using methods similar to the AHM approach, he posed the question of randomly-arriving quantities of supply. Viewed in an agricultural setting, his problem is to find the optimum quantity of a good -- say, wheat -- to plant, given that the quantity produced (arriving) is a random function of the quantity planted.

The summation of the work, presently existent, started by Arrow, Harris and Marschak, is to be found in the excellent Studies

in the Mathematical Theory of Inventory and Production, a collection of papers by Arrow, Karlin, Scarf and others (AKS). Through the first twelve chapters, this work attempts to find necessary and sufficient conditions for the existence of simple (one or two parameter) ordering policies. These chapters include and extend the work, in this direction. In addition to a review of the original AHM work, this book includes the dynamic-inventory problem, the inventory problem with fixed time lags, and the case of unknown-demand distributions.

The last chapters of the book return to the problem of parameter setting within a simple ordering policy. Included here is a lengthy discussion of an important new concept -- probabilistic delivery times.

This book, much like Raymond's, rounds out much of the existing knowledge in the field of inventory-control theory, as viewed from the Arrow, Harris, Marschak beginning. To understand the evolution and history of the entire field, requires, at this point, backtracking to pick up the chronological train left by preoccupation with the major school of thought in the 1950s.

## II. OTHER WORK AFTER 1950

Soon after the AHM paper appeared, Simon, in 1952,[171] presented another approach to the problem, that is of interest because it seems to have no antecedents in the earlier work of anyone. Noticing that the inventory process is not unlike problems in the field of servomechanism, Simon developed general problem solutions based on the electronic concepts. He spells out the basic similarities and introduces some costs. Included in his analysis, as a special case, is the concept of random arrivals of stock into inventory.

Vassian, in 1955,[189] approached the problem similarly, but with an entirely new decision criterion. Using, not costs or run-out probabilities, as almost everyone else has done, but stock fluctuations, Vassian proceeds to set up the basic model based on servo circuits, and to find the linear policy that minimizes the root mean square (standard deviation) of the stock fluctuations

from their desired level. He shows that the linear decision rule which minimizes stock variability is the classical ordering-cycle system discussed at length by Whitin.[200:30-78]

Simon and Holt continued the analysis of servomechanism systems, in their article, "Optimum Decision Rules for Production and Inventory Control", in 1954.[173] In it, the random-demand variable is introduced, as well as non-linear cost functions.

Unfortunately, the servomechanism approach has not received much attention, and extensive work is required to blend its possibilities into the main thinking on the problem.

Flagle, in 1956,[62] examined the inventory problem along the lines of Fry and Pitt. However, differing from these, he uses the basic concepts of the theory of queues, and describes the inventory system by its stated variables. On these, costs are superimposed (including a run-out cost) to arrive at a total expected-cost curve, from which the system parameters can be found by classical methods.

Freeman, in 1957,[65] dealt with the question of random arrivals, using cost concepts and a purchase model. His one-stage model assumes Poisson demand, no backlog of unsatisfied demand, and a two-bin (in the Whitin sense) policy. Taking costs as directly proportional to quantities, Freeman sets up a cost equation, which, through proper differentiation and differencing, yields the two parameters needed to solve the problem.

Harling and Bramson, in 1957,[78] again examined the problem of random arrivals. They took the deliveries to be normally distributed in time, and demand to be Poisson. Their model is basically static, and uses as a criterion the "level of protection", as opposed to the more usual cost concepts.

The major contributions to the problem of random arrivals have appeared since 1958. The work of Scarf and Karlin in the year 1958[13:chap. 16-17] has already been noted.

Morse, in 1958,[131 & 132] took up the problem of the analysis of an inventory system subject to random arrivals, assuming an s,S policy. Following the general problem of Scarf's finite model, he assumes Poisson demand when units are in stock, and Erlang time

lags to solve the finite model.

In neither Morse's nor Scarf's case was the system completely solved. From the stated variables, each writer determined the parameter settings, using criteria other than pure costs. Scarf comments on the general cost equation, but uses, as one decision criterion, his "figures of merit" (e.g., ratio of unsatisfied demand to all demand). Morse uses the classical "run-out probability" concepts of Fry, in addition to holding costs. With these criteria, and with the given stated variables, the optimum values of s,S can be determined by classic methods.

These works still leave, incomplete, problems in the important area of inventory systems subject to randomly-arriving units; and it would appear that this is a fruitful area of future research in extending the basic concepts of inventory theory.

## SUMMARY

In summary, we might say that an attempt has been made to trace the major thinking and the major contributions in the field of inventory-control analysis, from its inception in 1912 through the present. Raymond's monumental work, which effectively rounded out the "classical" approach, but left much to be desired, has been discussed. Also noted was the renewed interest in the subject, largely under the impetus of the work of Arrow, Harris and Marschak. The intervening and subsequent work has been traced in some detail.

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Vol. 44, 1957) is excellent, as is that of M. Gournay, R. Lewis and F. Neeland ("An Inventory Control Bibliography", Naval Research Logistics Quarterly, Vol. 3, 1955). The bibliography of Arrow, Karlin and Scarf, in Mathematical Studies in Inventory and Production Control (Stanford University Press, 1958), brings the field up to the near present. The following works, which have been used in the preceding paper, overlap, and extend the above works up to 1959. The addendum which follows the list below is a listing of some of the books and articles published more recently.

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## EXTENSION OF AVAILABLE INTEREST TABLES

This 42-page reprint is priced at $1 a copy (25% discount on purchases of more than 25); make check or money order payable to The Engineering Economist. The calculations were performed at the Syracuse University Computing Center. Included are an introduction and examples of the use of the tables.

# Effects Of Obsolescence On Tax Depreciation Practice

by PAUL T. NORTON, JR.

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To paraphrase an old saying: Everybody complains about the way obsolescence is handled in tax depreciation practice, but nobody has as yet found a solution that satisfies both the taxpayer and the tax collector. It is obvious that this problem is much too big to treat in detail in this short article,[1] but an attempt will be made to discuss several aspects of the problem which the writer believes either have not been fully understood by most persons, or else have not been explained sufficiently by those who advocate certain procedures. In order to develop the subject adequately, it will be necessary to investigate certain matters not directly concerned with tax practice.

## EFFECT OF OBSOLESCENCE IN DECREASING THE VALUE OF AN ASSET TO ITS OWNER

Many persons who advocate the use of straight-line depreciation do not seem to realize that under this method it is assumed that the earning power of an asset is as great in its last year of life as in its first year. (While maintenance expense tends to increase with age, this rarely compensates fully for the effects of obsolescence.) That straight-line depreciation charges often are not adequate was recognized by President Eisenhower in

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[1] For a more complete discussion, see E. L. Grant and P. T. Norton, Jr., Depreciation (The Ronald Press Co., New York, 1949; Revised Printing, 1955).

his message of January 21, 1954; the message included the following passage in respect to depreciation tax practice under the 1939 Code:

> The deductions allowed, especially in the early years, are often below the actual depreciation. This discourages long-range investment on which the risks cannot be clearly foreseen. It discourages the early replacement of old equipment with new and improved equipment. And it makes it more difficult to secure financing for capital investment, particularly for small business organizations.

Also, the House Committee Report, on the bill that became the 1954 Code, included the statement:

> The average machine or automotive unit actually depreciates considerably more and contributes more to income in its early years of use than it does in the years immediately preceding its retirement.

Also, the Senate Committee Report on this bill included the statement:

> The liberalized declining-balance method included in the bill concentrates deductions in the early years of service and results in a timing of allowances more in accord with the actual pattern of loss of economic usefulness.

It would be difficult to find more convincing proof that in 1954 President Eisenhower and both houses of the Congress believed that the accelerated methods permitted by the 1954 Code give, in most cases, a better picture of real profits than the straight-line method. Also, that where these accelerated methods are used for taxes they certainly should be used for the books as well.

Unfortunately, too many persons, who have been arguing since 1954 that depreciation tax practice should be still further liberalized, seem to consider such liberalization only from the viewpoint of providing an "incentive" for making desirable capital investments. Also, the many persons who believe that the 1954

changes went too far seem to have completely ignored the statements in the above three quotations.

It seems to the writer that past depreciation allowances have been inadequate, for both taxes and the books, whenever value to the owner is less than book value. Value to the owner may be defined[2] as: What one could afford to pay for this asset in comparison with the most economical one that could be substituted for it. However, value to the owner obviously can never be less than the greatest of second-hand value, scrap value, or value to the owner for some other purpose.

Everyone knows that second-hand values are likely to decrease rapidly in the early years of life, even where there are active second-hand markets. Most items of plant and equipment do not have active second-hand markets, and in such cases value to the owner is likely to decrease even more rapidly in the early years, especially where obsolescence is an important factor.

Value-to-the-owner calculations are seldom made as a measure of the adequacy of depreciation allowances, but, when made, they often indicate values much lower than the book values under straight-line depreciation.[3] A number of interesting paradoxes may be found in such calculations. For example, the more rapid the prospective future obsolescence, the more valuable may be the present obsolescent asset; also, the less the contemplated service, the greater may be the appraised value of the present asset. Failure to understand the significance of such paradoxes has resulted in errors in reasoning in some very sophisticated modern methods that have been proposed for use in engineering economy studies.

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[2]Ibid., pp. 16 and 23.

[3]Ibid., Chapter 13. See, also, P. T. Norton, Jr. and E. L. Grant, "Depreciation Estimates in Appraisals of Manufacturing Equipment", Transactions, American Society of Mechanical Engineers, July 1942, pp. 509-20.

## A BLIND SPOT IN DEPRECIATION ACCOUNTING

Because so many businessmen, and their accountants and engineers, fail to understand the effect of obsolescence in causing a rapid decrease in value to the owner, in the early years of life, there has been a "blind spot" in the thinking of these men, with respect to depreciation accounting. They concentrate their attention on the expected end of service life and on things that might affect that retirement date, and they do not pay attention to the many things that should influence the rate at which an investment is written off even though such things may not affect the retirement date.

Those persons whose thinking is affected by this blind spot seem not to understand fully: (1) that actual pre-1934 tax practice was rarely true straight-line depreciation; (2) that TD4422 was primarily intended to enforce a tax practice that most taxpayers claimed to have been using, but had not really been using; (3) that, as explained earlier in this article, the primary reason for the 1954 changes was the recognition by various agencies of the government that both loss of economic usefulness and contribution to income are generally greater in the early years of life.[4]

## OBSOLESCENCE PRACTICE OF INTERNAL REVENUE SERVICE

Officials of the Internal Revenue Service insist that their practice gives full consideration to obsolescence, but an examination of the present regulations proves that consideration is given

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[4] For further discussion of this important factor, see E. L. Grant and P. T. Norton, Jr., Depreciation, esp. chaps. 18 & 19. See, also, E. L. Grant and P. T. Norton, Jr., "An Engineering Viewpoint on Depreciation Accounting", Journal of Accountancy, Vol. 79, No. 6, June 1945, pp. 451-55; and P. T. Norton, Jr., "A Sequel to 'An Engineering Viewpoint on Depreciation Accounting'", Journal of Accountancy, Vol. 105, No. 6, June 1958, pp. 35-40.

only to factors that cause retirement and that no consideration is given to the more important effect of obsolescence in reducing value to the owner during life. We have here an excellent illustration of the blind spot discussed in the preceding section.

In this respect there has been no real change from the pre-1954 practice under TD4422. At that time, IRS practice was given on page 3 of the 1942 issue of Bulletin F, which reads, in part, as follows:

> Normal obsolescence is caused by factors which can be anticipated with substantially the same degree of accuracy as other ordinary depreciation factors, such as wear and tear, corrosion or decay. Accordingly, it is included in estimating the normal useful life of depreciable property, the effect of which is to include the allowance for normal obsolescence in the depreciation deduction.
>
> Extraordinary or special obsolescence rarely can be predicted prior to its occurrence. However, this does not necessarily imply that the asset already must have been completely discarded or become useless, but merely that a point has been reached where it can be definitely predicted that its use for its present purpose will be discontinued at a certain future date. Deductions for obsolescence of this type may be taken over the period beginning with the time such obsolescence is apparent and ending with the time the property will become obsolete.

IRS practice under the 1954 Code is given in Treasury Decision 6182, which became the Regulations Relating to Depreciation. The portion referring to obsolescence reads in part as follows:

> Section 1.167(a)-9 Obsolescence. The depreciation allowance includes an allowance for normal obsolescence which should be taken into account to the extent that the expected useful life of property will be shortened by reason thereof ... In any case in which the taxpayer shows that the estimated useful life previously used should be shortened by reason of obsolescence greater than had been assumed in computing such estimated useful life, a change to a new and shorter estimated useful life computed in accordance with such showing will be permitted.
>
> The accelerated methods of the 1954 Code do permit an

investment to be written off more rapidly in the early years of life than was permitted previously, but this does not fully take care of a rather common situation. Engineering economy studies often indicate that an asset is not quite obsolete enough to justify an immediate replacement, but also that the asset no longer has earning power sufficient for it to recover any part of its investment. Moreover, this equilibrium condition may continue for quite a few years. In addition, there are many cases where it is desirable, or even necessary, to retain an asset for many years merely for occasional or stand-by service. In both of these situations, if an investment in an asset cannot be recovered tax-free from its own earnings well before its retirement, there will not be a complete tax-free recovery of its investment from its own operations, even if the asset has been profitable enough in its early years to return its entire investment to its owner.

It is thus evident that there are many situations in which the present IRS practice does not fully take care of obsolescence even when the accelerated methods of the 1954 Code are used. In order to take care of such situations, it would be necessary to amend the law itself so as to accelerate still further the write-off rates in the early years of life, or to permit depreciation rates to be based in some way on lives that are less than actual average realized lives. The last named method was the one generally used prior to the issuance of TD4422 in 1934, although many taxpayers do not seem to be aware of the fact. It seems to the writer that one of the most promising of recent proposals for liberalizing tax depreciation practice is the bracket approach suggested by the National Machine Tool Builders Association and others, which is based on the method used in Canada. This will be discussed in some detail later in this article.

An examination of IRS practice on obsolescence would seem to prove that there is very little hope of obtaining an adequate recognition (tax-wise) of obsolescence, until the average taxpayer has a more thorough understanding of the effects of obsolescence and can make a better argument for a change in the law than he

has made up to now.

## TAX INCENTIVES VS. TAX DETERRENTS

In the opinion of the writer, the greatest single obstacle to an improved tax depreciation practice is the excessive emphasis by so many persons on the incentive aspects of further liberalization. During the years immediately following the issuance of TD4422, the writer had the privilege of serving with important business executives on many depreciation committees. There was much discussion of incentive taxation, including liberalized tax depreciation methods that were frankly designed to provide incentives for investments that otherwise would not be made. It will doubtless seem strange, to most present day-advocates of greater depreciation allowances for taxes, to learn that almost without exception the business executives on these committees of the 1930s strongly opposed all kinds of tax incentives, largely on the pragmatic grounds that tax incentives for one taxpayer were sure to be tax penalties for others, and, also, that the full effects of such tax incentives could not be predicted.

The 60-month special amortization privileges of World War II and the Korean conflict are often cited as having been enacted to provide incentives for investment in plant and equipment needed for national defense. The writer remembers well the discussions in 1940 at depreciation committee meetings, and separately with individual executives, when it became evident that large investments in plant and equipment would be required to produce goods needed for our own massive defense efforts and for meeting the demands of the countries then fighting Germany. No special incentives were required for these investments in depreciable assets; but they could not safely be made under the uncertainty as to how long the demand would continue, combined with the effects of low depreciation rates and an excess-profits tax.

In this connection, it is interesting to note the reasons

given by a subcommittee of the Ways and Means Committee, in its report of August 8, 1940 to the main committee, when recommending the 60-month amortization privilege which became part of the Second Revenue Act of 1940. The pertinent paragraph of this report reads as follows:

> The extension of existing facilities is a necessary and vital part of the national defense program. To obtain the needed facilities will require the investment of hundreds of millions of dollars. Your subcommittee has been informed by the Advisory Commission to the Council of National Defense that substantial amounts of private capital will not be invested in the construction of such facilities unless corporations are assured, in view of the fact that such facilities will be of use chiefly only during the period of national emergency, that they will be permitted to amortize the cost thereof over a shorter period than would be permitted under the depreciation provisions of the Internal Revenue Code.

It will be noted that this paragraph refers to the removal of a tax deterrent and not to a tax incentive. So many persons have so many and so diverse objections to incentive taxation that proposals for further tax depreciation liberalization are not likely to succeed if they are advanced merely as incentives for investments that otherwise would not be made. In fact, there is a danger that the 1954 liberalization itself may be repealed if advocates support it merely from the incentive angle.

How much better it would be if all concerned with depreciation liberalization would base their arguments on the fact that in most cases value to the owner decreases more rapidly in the early years of life and that it is logical for depreciation rates to be greater in the early years of life. Of course, this would mean that one should not use the straight-line method, with rates based on full average realized lives. It would also mean that if these liberalized methods were used for taxes they should also be used for computing book profits.

## THE BRACKET APPROACH TO TAX DEPRECIATION RATES

As stated earlier in this article, the writer believes that the bracket approach proposed by the National Machine Tool Builders Association and others is worthy of study among proposals for further depreciation liberalization. The method definitely considers the effects of obsolescence during life, and a somewhat similar method has been used successfully for quite a few years in Canada. However, there are technical factors that do not seem to have been considered, by most advocates of the method, that may make it less attractive in the long run than it appears to be at first glance.

As explained in its policy statement of January 2, 1959, the bracket approach proposed by the National Machine Tool Builders Association would classify all depreciable assets into a relatively few groups. Each group would be given a bracket of lives or depreciation rates which taxpayers might use for any assets in the group. Lives or rates outside the bracket limits could be used if approved by the IRS. According to the policy statement:

> The range of lives for each bracket would be established in such a way as to reflect present-day thinking on technological obsolescence, and a minimum of attention would be paid to past patterns of actual retirements and replacements. The result would be much shorter lives for most assets than those now listed in Bulletin F. For machine tools, the suggested range is from 7 to 10 years. This would be more comparable to allowable rates in other countries.

While this bracket approach is based on the Canadian method, there are important technical differences. The Canadian method is not even called depreciation but carries the name of "capital cost allowances". Also, the declining-balance method must be used, and a taxpayer may use any rate up to the stated maximum for the class or category. The writer understands that, accounting-wise, all the assets of any category are included in an open-end group

account, with additions and retirements handled as they occur.[5]

A principal reason why the bracket method is such a desirable approach to the problem is that it is so much like the practice used prior to the issuance of TD4422 in 1934. Prior to 1934, most taxpayers claimed to be using the straight-line method, but they were not really doing so because the rates used were higher than those corresponding to full average service lives. For example, a 10 per cent rate was quite generally used for machine tools, although it should have been evident to all that actual average service lives were longer than the corresponding 10 years. This was really a very good method, especially when used with item depreciation accountancy, but it had one bad result that had much to do with the issuance of TD4422 and the subsequent inadequate tax depreciation allowances. Most persons seem to believe that the only purpose of TD4422 was to secure additional revenue by reducing depreciation rates. This was an important purpose, but it can be shown that, in the light of the 1934 situation, the change that took place in 1934 was a logical one.[6]

When the straight-line method is used with rates that are greater than those corresponding to actual service lives, investments are written off before lives come to an end. This is satisfactory under the item straight-line method, as depreciation charges merely end when the investment is written off. However, by 1934 the Treasury was beginning to think in terms of the statistical approach to physical property mortality, combined with a belief that depreciation rates should be based on the best available evidence of full average service lives.[7]

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[5] For an extensive discussion of the advantages of open-end group accounts under the declining-balance method, see, again, E. L. Grant and P. T. Norton, Jr., Depreciation, esp. pp. 401-27.

[6] Ibid., esp. pp. 359-61.

[7] Ibid., esp. pp. 211-20.

Secretary Morgenthau's letter of January 26, 1934, to Ways and Means Committee Chairman Doughton contained the following paragraph:

> The bureau has for several months had under consideration more effective means of administering the depreciation provisions. This study has shown that through past depreciation deductions many taxpayers have (as shown by facts now known to exist) built up reserves for depreciation which are out of proportion to the prior exhaustion, wear and tear of the depreciable assets. If past methods are continued, the amount representing the basis of the assets will be completely recovered through depreciation deductions before the actual useful life of the assets has terminated.

If the bracket method were permitted by an amendment to the Code, and the straight-line method were used, the situation referred to by Secretary Morgenthau would soon again be with us. This unfortunate situation could, of course, be eliminated if the declining-balance method were used.

The writer believes that it is very unfortunate that so many financial executives and accountants have such a strong aversion to the declining-balance method. There is strong evidence that originally the declining-balance method of the Canadian system was bitterly opposed by these men; but that after years of experience with the method, nobody in Canada wants to change it. Most companies who have used the declining-balance method seem to believe that this method with open-end group accounts is far superior to the straight-line method or any other method that will meet Treasury requirements. The writer believes that the bracket approach would be improved by going all the way to the Canadian system, with possible changes in rates and classifications in order to more adequately meet our own conditions. This would eliminate completely the matter of average service lives, which has been so troublesome ever since 1934, as it would involve using declining-balance rates only.

If it were found that the government insisted on retaining the average-realized-life concept, the writer believes that the

best solution would be to retain the present declining-balance method of the 1954 Code, with a greater multiple. For example, by increasing the multiple over the present limit of twice the straight-line rate, almost any rate of obsolescence could be taken care of, as well as the situation where assets are retained for stand-by service.

## SUMMARY

The information in this article may be summarized as follows:

The depreciation liberalization of the 1954 Code was intended primarily to provide allowances more in accord with the actual pattern of loss of economic usefulness, and to remove investment deterrents rather than provide investment incentives.

When considering the effects of obsolescence, too many persons concentrate their attention on things that cause asset retirement and do not pay enough attention to things that cause decrease in value to the owner during life. Also, the average person does not seem to understand that actual pre-1934 practice was rarely true straight-line depreciation, even though it carried that name.

The obsolescence practice of the IRS considers only factors causing asset retirement and does not consider in any way the decrease in value to the owner during life.

The bracket approach to further liberalization, proposed by the National Machine Tool Builders Association and others, deserves careful attention; but it may well be that a method even closer to the Canadian system may be still better.

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# Interest-Rate Theory

A Review of: AN INTRODUCTION TO THE THEORY OF INTEREST
By Joseph W. Conard
University of California Press, 1959
375 pp. $7.50

By: Seymour Friedland
Associate Professor of Economics
Claremont Graduate School

Professor Joseph W. Conard presents an excellent critical review of interest-rate theory in this book. The approach used is reminiscent of that used by Bohm-Bawerk, who made a critical review of interest-rate theory to the late 19th century.[1] Conard's contribution is essentially expository. The analysis is generally conducted with marvelous clarity and prevision. In the preface, Professor Conard promises a future volume(s) which will contain new work -- a treatment of interest-rate structure under conditions of market imperfections, uncertainty and dynamic elements, including empirical tests. This, too, is similar to Bohm-Bawerk, who presented his own theory in a separate volume.[2] These parallels, of which Professor Conard could not be completely unaware, should not be pursued too far. The flavor and boldness of the works are quite different. Bohm-Bawerk is quite outspoken where Conard generally softens his criticisms with modifications. This may simply show that modern economists are more timid than were their predecessors. On the other hand, Conard's carefulness may reflect the fact that we know more economics today. Whatever the cause of the differences in flavor between modern and older works, for mildness of tone is observable in most modern works, it is regrettable that the boldness has gone.

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[1] Eugen Von Bohm-Bawerk, Capital and Interest (Libertarian, 1890).

[2] Eugen Von Bohm-Bawerk, Positive Theory of Capital (Libertarian, 1894).

Professor Conard divides his book into three parts. The first is concerned with non-monetary theories of interest. The second part deals with monetary theories of interest. Part three treats the structure of interest rates under conditions of perfect competition, certainty, and static conditions.

The difference between monetary and non-monetary theories is not easy to specify. Non-monetary theorists were concerned with the long-run determinants of the interest rate and capital formation. Their arguments center on variables such as the productivity of capital and preferences between present and future income. They recognized the existence of aberrations from the normal or "natural" rate of interest in the short-run (duetto monetary phenomena), but, by and large, were not interested in such deviations. After a careful review of the non-monetary theorists, Conard chooses Irving Fisher[3] as having presented the most satisfactory theory. It is inadequate in the sense that it excludes the effect of the money supply on the interest rate. However, it does relate the effects of time preference, present and future income distributions, and investment opportunities,in generating a real rate of interest. Fisher's rate of return over cost is still used in some aspects of capital budgeting.

Although non-monetary theorists generally ignored the effects of money-supply variations, monetary theorists are not concerned exclusively with monetary phenomena. Wicksell, for one example, specifically interrelates the natural rate of interest, which is akin to the interest rate discussed by non-monetary theorists, with the money rate of interest.[4] Monetary theorists have been concerned with the cyclical stability of income. In a sense, most non-monetary theorists were interested in partial equilibrium problems rather than general equilibrium problems. Monetary theorists were

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[3] The Theory of Interest (The Macmillan Co., New York, 1930).

[4] Knut Wicksell, Interest and Prices (The Macmillan Co., 1936).

most interested in the interreactions between interest and the determination of income.

Keynes is the best-known of the monetary theorists.[5] According to Keynesian theory, the interest rate is a monetary phenomenon determined by the money supply and the demand for money. Thus, the Keynesian analysis is based on stock-type variables (stocks of money). This has been labeled "liquidity preference doctrine", since an important variable is the preference for money as opposed to other assets. In contrast, we may consider the Robertsonian doctrine of loanable funds.[6] In this system, the interest rate is determined by the demand for and supply of securities. Money is a flow in the loanable-funds approach. As Professor Conard points out, both doctrines will generate the same interest rate with proper definitions, under most conditions. The important differenc is that the behavioral assumptions underlying the two doctrines are quite different. Conard believes that the liquidity-preference approach embodies more reasonable behavior assumptions, but a final resolution must await more empirical work.

The so-called Swedish-loanable-funds[7] approach differs sharply from the Robertsonian approach in terms of behavioral assumptions. The Swedish approach is concerned with differences between expected and realized values which generate the supply and demand for securities. Again, resolution as to which theory is "right" awaits empirical investigations of the underlying behavioral assumptions.

The remainder of Part II is concerned with the problem of fitting the price level into the interest-rate models. In the classical models, this is no problem, since full employment is

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[5] The General Theory of Employment, Money, and Interest (Harcourt, Brace & Co., New York, 1936).

[6] See, for example, J. S. Bain, Pricing, Distribution and Employment (Holt, Rinehart & Winston, New York, 1953), pp. 626-41.

[7] B. Ohlin, "Some Notes on the Stockholm Theory of Savings and Investment", Readings in Business Cycle Theory (Blakiston's Sons & Co., Philadelphia, 1944), pp. 87-130.

assumed throughout. Thus, variable prices are one of the very important elements in explaining the economic process. In the Keynesian model, however, employment can vary. As a result, the economy can adjust to an equilibrium either through changing prices or by variations in employment. In terms of economic policy, the analysis, albeit complex, is vital. The issue involves the effectiveness of monetary policy as an anti-inflationary device within the context of a growing economy. Another application of this issue is in the area of economic development, where attempts to increase aggregate demand may be frustrated via the inflation route, because the real problem lies in low productivity.

To this point, the discussion has been in terms of a single interest rate. In fact, there exists a structure of rates. Within the structure, the rates vary because of maturity dates, uncertainty, risk, and market imperfections. In Part III, Professor Conard approaches the problems raised by consideration of rate structure. He presents the neoclassical view of the matter which abstracts from risk, uncertainty and market imperfections, and concentrates on the effect of varying maturity dates. In this simple case, the difference between current short-term and long-term prices will reflect expected future interest rates on securities, in such a way that the current rates for long-term securities will be roughly the average of future short-term interest rates. While this is not new, Professor Conard's next step is interesting. He develops a perfect foresight model, which is the neoclassical model sketched above, modified for the assumption that people really believe in and stick with their expectations of the future. He compares this to the general neoclassical model and tests both models against data on government securities. As might be expected, the perfect foresight model does not provide a satisfactory explanation of term-yield relationships. However, the neoclassical model stands up fairly well under the tests used.

Since expectation shifts are caused by variables other than interest rates, the general neoclassical model is not satisfactory in itself, but is quite usable in a larger model. Conard presents such a general equilibrium model. It is interesting that the

simple neoclassical model stands up so well. Although this has not yet been shown, it may turn out that the neoclassical explanation of interest-rate differentials is a more efficient explanation than are models which treat market segmentation, risk and uncertainty explicitly.

Now that the broad outlines of the book have been sketched, we may turn to the problem of evaluation. Has the book achieved th author's goal? The answer must be yes. The book contains a comprehensive critical review of the major elements of interest-rate theory. The materials have been handled in a thorough, highly competent, and, at times, even brilliant manner.

Is it worth reading for those who are not economists? Any answer to this would be quite presumptuous. Yet the materials covered are vital as background and as analytic tools for those interested in money-market and capital-market variations. For those interested in capital-budgeting problems, the book is less satisfactory. This is not a criticism, however. The theoretical problems of capital budgeting are not very difficult. Aside from the formidable practical problems of organization and forecasting, the capital-budgeting problem is simply a matter of arraying investment projects (broadly defined as anything involving current expenditure, with receipts coming back, in part, in future periods) in order of desirability, and choosing the best means of financing.

If profitability is the index for desirability, a discounting procedure would be used to facilitate arraying the choices. There is some debate as to whether the product of the discounting procedure should be a rate of return or a present value. Those who advocate present value point out that the rate of return is ambiguous under certain conditions. Specifically, if the investment generates alternating negative and positive returns in different future periods, the discounting procedure may generate more than one rate of return.[8] This can be treated in one of two ways.

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[8] M. J. Bailey, "Formal Criteria for Investment Decisions", Journal of Political Economy, Vol. LXVII, No. 5, Oct. 1959.

Negative returns can occur often because we discount the difference between two streams of returns, as in the replacement problem. The negatives disappear if we directly discount the separate streams of returns. In other cases, negative values can be eliminated by expanding the time period used in discounting, so as to combine negative periods with positive periods.

Another argument for present value is the case where two competitive projects (and most projects are competitive unless unlimited funds are available) have rates of return which are very similar. If one project is much larger in dollar amounts of returns and costs than the other, the rate-of-return criterion may favor the smaller project, although, in fact, the larger project is more profitable.[9] It is hard to tell how serious a problem this is in practice. In the event such projects are under consideration, and the larger project is rejected under the rate-of-return criterion, a second test can be made. This consists of discounting the differences between the returns of the two projects back to the difference in costs. If the result is a higher rate of return than that generated by the smaller project alone, the larger project should be preferred.

The major weakness of the present-value approach is that it is not easy to choose the proper discount rate. Too high a rate biases decisions against long-term projects. Too low a rate biases decisions against short-term projects. The appropriate rate is the cost of funds needed to finance the project. Yet, if we choose among sources of funds on the basis of cost of funds, the sources of funds are determined simultaneously with the chosen investment projects. If the capital-budgeting process has as an aim the selection of funds by a cost criterion, the use of present value as a criterion for investment projects means that we have an under-determined system -- two equations and three unknowns.

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[9] J. Hirshleifer, "On the Theory of Optimal Investment Decision", Journal of Political Economy, Vol. LXVI, No. 4, August 1958.

The third issue in capital budgeting is whether firms should choose among sources of funds on the basis of costs. The purpose of such a basis for choosing is that it "satisfices" the stockholders. However, if security holders adjust their portfolios appropriately, they can do better than satisfice, regardless of the firm's capital structure. The theory is impeccable[10] but it does not follow that the theory describes the real world. Stockholders may be faced with institutional rigidities which do not permit manipulation of portfolios (buying on margin, etc.) to the extent implied by the theory. Further, the price differences among different securities apparently reflect other institutional rigidities, such as investment regulation applying to institutional investment. Such differences would retard the kind of adjustment discussed in the theory. Lastly, if stockholders do not manipulate portfolios in the manner indicated by the theory, firms which do choose among sources of funds on the basis of the cost of capital will have a relative advantage over firms which do not. If the theory is true, the problem of determining present value is resolved. The firm would discount using the average cost of capital. Since published attempts[11] to prove or to disprove that the "portfolio adjustment" scheme is a fair description of reality are far from convincing (and there is a question as to whether the kinds of tests attempted to date are at all appropriate to the problem), we may have resolved one problem by replacing it with another.

To the extent that the problems described are theoretical at all, they are trivial. It is a tribute to the many capital-budgeting theorists that this is so. The problems remaining in this area are mainly empirical and organizational. And it is with this in mind that we await Professor Conard's promised second volume, which will center on empirical tests of interest-rate theory.

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10 Franco Modigliani and M. H. Miller, "The Cost of Capital, Corporation Finance and the Theory of Investment", American Economic Review, Vol. XLVIII, No. 3, June 1958.

11 See papers by J. R. Rose and David Durand, and reply by Modigliani and Miller, American Economic Review, Vol. XLIX, No. 4, Sept. 1959.

BOOK REVIEW

A Review of: ELEMENTARY DECISION THEORY
By Herman Chernoff & Lincoln E. Moses
John Wiley & Sons, Inc., New York, 1959
364 pp. $7.50

By: William T. Morris, Professor
Department of Industrial Engineering
The Ohio State University

This book is one of the first, and to date one of the best, attempts to put the work of Abraham Wald into the hands of students and others who are not professional statisticians. Wald, and those who took up the exposition of his ideas -- Blackwell and Girshick, for instance -- wrote in a highly sophisticated fashion. What they had to say is of immense importance to engineers, scientists, and businessmen; but the lag between the professional publication and anything like wide application has been unfortunately long.

The basic notion of "modern statistics" or "decision theory" is simple enough. The moment one steps outside the realm of the pure search for knowledge, one is interested in taking action on the basis of experimental evidence. In "classical statistics" many problems were formulated in terms of hypothesis tests, and the imperfections of inference were expressed as probabilities of Type 1 and Type 2 errors. The modern view is one of a choice between alternative courses of action, considering explicitly the cost of collecting data and the consequences of taking various actions as a result of processing data. This latter view is obviously closer to the problems of those who operate in a world of action, assisted by applied science.

The book begins with an introduction to the usual abstraction of the decision process, in terms of alternatives, outcomes, states of nature, and probabilities. It then builds up the necessary background in three chapters dealing with data processing, probability theory, and the Von Neumann-Morgenstern notion of utility. Chapters 5 and 6 present the core of the theory of

statistical decisions under risk and uncertainty. The last four chapters develop the problems of classical statistics (estimation, hypothesis testing, and confidence intervals) within the framework of decision theory. Chapter 8 is a noble attempt to give the reader some feeling for the great artistic step of portraying the complexities of reality with simple abstractions.

As an introduction to contemporary statistical reasoning for engineers, this book is first rate. It is written in an easy instructive style, with plenty of examples set into the text. The examples are artificial and sparked with humor, but part of the excitement of reading is thinking of applications to one's own work. Along the way, one picks up a good introduction to set theory and its uses. Above all, perhaps, it attempts to make the reader aware of the violence which is done to the niceties of statistical logic, in practical applications. This is one of the more important consequences of the action-oriented view of inference.

It might be found wanting in two respects. It makes only the barest allusion to personalistic or subjective probability. Because of the unclear position of this concept, in engineering today, some will see this as a wise choice. Others may wish for an illumination of what can be done in the absence of relative frequency evidence. Secondly, while an excellent exposition of utility theory is given, as is required for the avoidance of some very fundamental questions, one might hope for some exploration of the practical possibilities for utility measurement. If the consequences of our actions can be logically evaluated in expected cost and expected profit terms, utility theory will prove it to us. If, on the other hand, we must logically deal in expected utilities, then one faces the awesome task of going to the board of directors and measuring their utility function.

As a handbook for those who offer advice to managers, the book leads one to raise several questions. For example: Can utility be measured in a business firm? Will managers accept the deductive consequences of the theory, namely, that (even in one-time decisions) they should always choose so as to maximize expected utility? Will a manager let his actions be determined in

part by the flip of a coin? The difficulties here are not, of course, the fault of the book, but of the state of the art.

For those whose special interest is engineering economy, the book may be generally suggestive. Although it does not deal with exactly the sort of problems we normally regard as a part of the field, it is clear that our problems basically involve collecting data and trying to take some sensible action on the basis of the data. Thus the general form of the logic is applicable. Exactness of application is limited by the fact that engineering economic data is seldom in the neat form of random variables with known probability distributions, and that the problems tend to be highly complex. Many will agree, however, that here we begin to see more clearly the path along which the logic of induction and choice is leading us. Our ability to follow this path, as advisers to management, depends on how far ahead we can see.

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BOOK REVIEW

A Review of: CAPITAL, INTEREST AND PROFITS
By B. S. Keirstead
John Wiley & Sons, Inc., New York, 1959
180 pp. $4.00

By: Michael Belshaw
Assistant Professor of Economics
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In spite of its deceptive title, this admirable little book contains very little that would be of professional interest to the engineering economist. Indeed, the author does not pretend to focus his attention in this way, but states as his general theme that "we are interested in how new capital is formed in a progressive economy". While he wanders through this problem, he devotes, on the most elastic assumption, only about 42 pages to matters of interest to readers of this journal.

In Part I, chapters are concentrated on Keirstead's sometimes heterodoxical views on microeconomics, and an understanding of his position requires familiarity with marginal analysis, and the theories of Hayek, Bohm-Bawerk and Fisher, all of which come under vehement attack. Comprehension of Keirstead's position is not facilitated by his habit of inserting diagrams ungraced by explanations in the text. Nevertheless, some of the insights are penetrating and timely. The comments on interest determination reject Fisher's time-preference notions on the grounds that the "rich" who are the most important source of voluntary savings "do not need to be offered a reward as an incentive to save". On the other hand, it is more debatable that the rate of interest depends primarily on governemt policy because "the power of government in borrowing is so great that its announced price for loans cannot be disputed". This argument is belied by the diminished acceptance of some Treasury issues in recent years.

Other matters of possible interest to the engineering economist are the sections bravely trying to untangle Bohm-Bawerk's conception of capital as "roundabout production" and to define

the process of entrepreneurial decision-making. As Keirstead concedes, more thorough approaches to this latter problem have been attempted recently in the literature of both economics and business administration. One interesting by-product of Keirstead's rejection of marginal analysis is the conclusion that competition calls forth greater profits than monopoly. This conclusion is based on the ability of the great corporations to control costs and manipulate demand and thus reduce the risk factor in profits. This statement may, however, surprise those corporation executives actually faced with these problems.

Part II is devoted more to the macroeconomic problems of growth and economic stability. Chapter VIII of the economic development of Newfoundland is clearly the most worthwhile in the book. Chapter VII on Conventional Societies and how they finally generate dynamic capital is quite good, but for the reader interested in such problems, more well-rounded and penetrating analyses are becoming available.

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BOOK REVIEW

A Review of: PROPOSED PRACTICES FOR ECONOMIC ANALYSIS OF RIVER BASIN PROJECTS
Prepared by the Subcommittee on Evaluation Standards, Interagency Committee on Water Resources.
U. S. Government Printing Office, May,1958
Revised ed. 56 pp. 25 cents

By: Robley Winfrey, Chief
Highway Needs and Economy Division
United States Department of Commerce
Bureau of Public Roads

This edition is a revision of the original May 1950 publication. The same format, size (6 x 9 inches), and color have been retained. Because of the long, involved title, the publication, in both editions, is popularly called "The Green Book".

The revised edition contains few changes. These consist mainly of a tightening up of the wording, here and there, to achieve clarity, and of a rearrangement of some of the material. Thus the new edition is, basically, quite representative of the original publication, paragraph-by-paragraph and page-by-page. Also, it is, like the original, regarded as an interim report, for the Interagency Committee on Water Resources and the Subcommittee on Evaluation Standards are still studying the problem of the economy of public-works projects, and expect at some future date to issue another report.

Within the several federal agencies, there have existed differences in concept, in procedure, and in methods of measurement of the benefits and costs of public works in the water-resource field.

The Committee is interested in developing a systematic, consistent, and theoretically sound framework for the economic analysis of river-basin projects and programs. The Committee desires to do this irrespective of current practices or legislation or administrative limitations. The 1958 "Green Book" recognizes that practice in benefit-cost analysis and allocation

of costs, by the various participating agencies, has been improved as a result of the publication of this material. However, it is believed that further acceptance of the recommendations set forth in the book would be followed by an improvement in formulation, a better selection of projects, and more effective river-basin development.

This publication does a good job of delineating the basic principles and concepts of the engineering-economy type of analysis for river-basin projects. To quote: "The ultimate aim of river basin projects and programs, in common with all other productive activity, is to satisfy human needs and desires. The objective of economic analysis in planning river basin and watershed programs is to provide a guide for effective use of the required economic resources, such as land, labor, and materials, in producing goods and services to satisfy human wants, by determining whether economic resources would be used more effectively than would be the case without the project."

The book recognizes the inadequacy of the private market as a basis of valuation of public works and services, from a public viewpoint. It further recognizes that there are many beneficial consequences of water-resource projects, which result in social gains such as improvement in health and enjoyment of recreation, that cannot be evaluated in monetary terms by use of the market system. Despite these limitations, however, the book relies upon the market-price system as a starting point for formulation of principles for the benefit-cost evaluation.

It deals systemically with (1) project and program formulation, (2) measurement of benefit and cost, and (3) application of principles to various project purposes.

There is little to criticize and much to commend in the general treatment of all the factors involved in the analysis of engineering economy. The publication does recommend consideration of the change of price, when such change of price is easily foreseeable and would result in a factor to be examined in the analysis. However, it recommends against any consideration of the changes in the value of the dollar over a long period. It

states, specifically, that "deflationary shifts in long-term average prices should similarly be excluded".

With respect to interest rates, the following may be quoted: "It is recommended that estimates of benefits and costs accruing at various times should be made comparable by adjustment to a uniform time basis, through the use of projected long-range interest rates. Pending the development of such rates, the average rate of return, i.e., yield on long-term federal bonds over a sufficiently long period of time to average out the influence of cyclical fluctuations, is considered appropriate for uniform application by all agencies, on the condition that adequate allowance has been made for uncertainities and risk. If such allowance is not possible, a component for risk should be included in the interest rate, as may be the case for irregularly accruing benefits and associated costs."

The practicing agencies of government generally use low interest rates, such as the average interest rate the United States government is now paying on its indebtedness. This practice fails to separate the rate of return from the cost of financing, as do a large number of individuals who feel that the interest rate to be used in the analysis for economy is the rate at which money could be borrowed on bonds. This feeling is opposed by individuals who think that the rate should be one which is more nearly comparable to the cost of money to the common public. Many individuals believe that the interest rate should not be less than rates used in the analyses by public-utility companies.

The recommended length of period of analysis to be used in the calculations is the best forecast of useful life that can be made, with the maximum of 100 years. It is recommended that salvage be included where it can be reliably estimated. In connection with the period of analysis, there is no discussion of the effect of a long number of years on the benefits to be received. In other words, the benefits calculated would have to continue for the full period of analysis for which the costs of capital investment were calculated.

Appropriate treatment is given, also, to the handling of

tangible and intangible consequences, adjustments for economic activity, treatment of cost of affected public utilities, acquisition of land, treatment of taxes, treatment of displaced facilities, and consequential damages.

Under the section devoted to application of these principles, discussion is given in these areas: irrigation and drainage, flood control, navigation, electric power, municipal and industrial water supply, recreation and wildlife, and water polution. The book also devotes a few pages to cost allocation for multiple-purpose projects.

"The Green Book" is heavy reading, because it is packed full of pertinent statements. Each statement requires considerable study before its full impact is ascertainable; and it is likely that, if the publication were reviewed critically by individuals of non-government background, different viewpoints would be taken. It is recognized that government is not the same thing as private industry; on the other hand, when it is realized that the same private citizens support both private industry and government, it appears that the same basic economic principles would apply to the analysis of any proposed investment.

The publication is recommended reading for everyone engaged or interested in problems of engineering economy. Although it is devoted primarily to water-resource types of public works, the basic principles established in it, and its discussions, apply equally well to any government work for which an analysis for engineering economy would be appropriate.

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BOOK REVIEW

A Review of: DECISIONS UNDER UNCERTAINTY
Drilling Decisions by Oil and Gas Operators
By C. Jackson Grayson, Jr.
Published by the Division of Research,
Harvard Business School
1960 397 pp. $6.00

By: Gordon C. McKeague
Research and Development Department
American Oil Company

This book is recommended reading for those making drilling decisions and those interested in decisions under uncertainty. The value of the book lies in illustration of how decision-making tools may be applied to a real situation. Although no new concepts or ideas are presented, those used are well selected and appropriately applied.

The first part of the book describes drilling decisions and related activities as observed during Grayson's research. Technical information is included only as necessary to explain material relevant to drilling decisions. Before describing drilling decisions along with illustrative cases, Grayson takes the reader by the hand and describes, in easily-read text, what a drilling venture really is. Beyond this, he covers organization and procedures used in drilling-decision making, and factors influencing drilling decisions (geological, economic, and personal); and he closes this part of the book with a description of decision processes and a chapter on trading. The second part of the book shows how, in facing the problems described earlier, drilling decisions may be made by using more quantitative techniques. Here he investigates and describes the application of statistical techniques, the concept of utility, and information decisions; and he closes with a chapter on simulation. In the chapter on simulation, a drilling-decision game is presented.

A book of this sort, especially when research is limited by time and money, would be considered worthwhile if it takes a step forward in an area or problem of significance. This much the

book accomplishes. There are places in the book where an unsympathetic reader might ask for more facts and less rhetoric, yet, on balance, the book meets the goals Grayson had in mind as he undertook his research work.

He states that the focus of his research, in the area of capital budgeting, bears directly on this point -- the effect of uncertainty on investment-decision making. He does not specifically cover the effect of uncertainty on decision making, to the extent of placing the way to make decisions under uncertainty before the reader. Thus there is no basis for testing his arguments in favor of more analytical approach. Grayson himself indicates that this is just the beginning in research and analysis, covering a very wide and complex area. Perhaps one of the things that would be reasonable to undertake, in continuing this work, would be the comparison of drilling decisions made with the use of statistical decision theory, as suggested by Grayson, with those made using seat-of-the-pants judgment.

The title of the book suggests that one will learn how to treat the uncertain aspects of making decisions. While it is true that the alternatives in each case are considered, and each alternative assigned a likelihood of success or failure, there is little consideration for the very complicated problem of identifying the alternatives in the first place. It seems clear that decisions under uncertainty are no better than the best alternatives conceived. It is true that the alternatives should be conceived and identified by the person or organization involved in the specific drilling decision. The point is that, should these alternatives be sufficiently numerous, one of two conditions might exist. First of all, it is possible that the conceiving of alternatives may be worth more than the rigorous solution of the drilling-decision problem. Secondly, the number of alternatives may be, in fact, so large that either time or computational capability may leave seat-of-the-pants the winner in a comparison with the more rigorous techniques.

An asset of the approach suggested by Grayson would be the formalization of thinking in this complex area. Some of the

examples used by him suggest that firms making drilling decisions have seen fit to formalize data accumulation and presentation of drilling opportunities in a surprisingly rigorous manner.

The author discusses the measurement of utility, and makes an attempt to establish utility for several individuals. This is, in itself, an interesting piece of work. Beyond his level of effort, it would seem appropriate to determine whether utility factors apply over a reasonable period of time. Since the results of drilling decisions are so varied in return, it may well be that the variation in utility from time to time exceeds the range within which utility might vary without having a major effect on any given decision. Grayson faces up to the problem of measuring utility, and describes his approach in considerable detail.

This involves placing a number of opportunities before the people who must make drilling decisions, and plotting their utility curve, as it were, based upon their response to the opportunities presented. The simulation game proposed by Grayson is interesting, but one should not purchase the text simply to obtain this. It appears that the game is just in the initial stages of development and has not been fully de-bugged, nor all of the options worked out. In fact, Grayson points out that the game has been played only a limited number of times, and that it is suggested as an idea rather than as a finished tool.

In summary, one must agree with the author that this book is just a beginning of research into a very complex problem. In fact, as he says, a "very small one at that".

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| Maffei, Richard B. | 5 | 4 | 41 |
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| Norton, John H. | 5 | 2 | 29 |
| Norton, John H. | 6 | 1 | 9 |
| Norton, John H. | 6 | 3 | 40 |
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| Norton, Paul T., Jr. | 6 | 4 | 34 |
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| Roth, William J. | 6 | 3 | 47 |
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| Strassmann, W. Paul | 5 | 4 | 59 |
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| Chang, Andrew Tsu-chao | 5 | 2 | 13 |
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| Ullmann, John E. | 5 | 2 | 40 |
| Ullmann, John E. | 5 | 3 | 1 |
| Ullmann, John E. | 6 | 1 | 29 |
| Vasic, Filip | 6 | 1 | 1 |
| Ward, Richard J. | 6 | 1 | 40 |
| Weston, George F. | 5 | 1 | 22 |
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